One-step Thresholding for BOLD Signal Detection in Accelerated fMRI

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Introduction: Functional magnetic resonance imaging (fMRI) with blood-oxygenation-level-dependent (BOLD) signal is fundamentally limited by the time required to acquire each volume. Standard EPI sequences with statistically advantageous TRs of 1-2s are typically restricted to acquiring no more than 16-32 slices with a typical 3 mm^3 isotropic resolution. This covers only about 40-80% of the cerebral cortex. A fast imaging technique would enable full volumetric coverage at short TRs. Previous work [1] has proposed the use of a data-dependent sparsifying transform and a complex nonlinear reconstruction technique to estimate the BOLD signal from an accelerated acquisition. In contrast, this work proposes a **simple** and **fast** one-step thresholding (OST) algorithm for the detection of BOLD signal. Results from the proposed method at 2x-acceleration demonstrate close agreement with the fully-sampled reference.

Theory: Equation 1 presents the model that relates the measured k-space data *k* to the unknown vector of interest *b*. The matrix Φ denotes the undersampled Fourier transform operator, *C* represents the coil sensitivity information, and *X* contains the hemodynamic response function (HRF) convolved with the time courses of the stimulations. Together, these three matrices form the measurement matrix. Assuming two stimulus conditions, the vector *b* consists of two elements for each voxel, each reflecting the activation resulting from the corresponding condition. The nonzero pair-wise differences of the vector *b* reflect BOLD signal activation, which is expected to be quite sparse. This work proposes to use a fast and straightforward OST algorithm to determine the location of these nonzero pair-wise differences. Recently Bajwa et al. [2] have shown that OST can reliably determine the signal support in the compressed setting when easily calculated conditions of the measurement matrix are verified. OST is performed by first backprojecting the measurement data (Eq. 2) and then thresholding the resulting vector (Eq. 3). In Eq. 2, the term *C**, for example, denotes the conjugate-transpose of *C*.

$$k = \Phi C X b \quad (1)$$

$$y = X^* C^* \Phi^* k \quad (2)$$

$$\hat{b} = (y > \lambda) \quad (3)$$

Methods and Results: A block-designed experiment with right-finger-tapping (RFT) and rest (R) blocks was used to test the proposed approach. The experimental design is shown in Figure 1. The subject was instructed to maintain a fixation point and to tap fingers on the right hand during the RFT blocks and to remain still during the R blocks. Data were collected from a 3T MAGNETOM Trio system (Siemens, Erlangen, Germany) using a 2D-multislice single-shot T2*-weighted EPI sequence with TE\TR = 30\2000 ms and flip angle = 84 deg. The acquisition matrix size was 64x64 at 29 oblique-axial slices with a spatial resolution of 3 mm^3. Data from the first time point were used to calculate coil sensitivity information after which the first block was discarded. The remaining data were retrospectively downsampled in a 64x80 (number phase-encodes x number TRs) dimensional space according to a variable-density scheme [3]. The OST algorithm was used to detect activated regions. The threshold parameter λ was chosen to keep an uncorrected p-value below 10^{-4}. Reference estimates were calculated from the fully-sampled data via the general linear model (GLM) at the same threshold. All processing was done in Matlab (The Mathworks, Inc., Natick, MA). Figure 2 displays activation maps from three slices from the fully-sampled reference and the proposed method at 2x-acceleration. Activation is concentrated in the left primary motor cortex (see arrows).

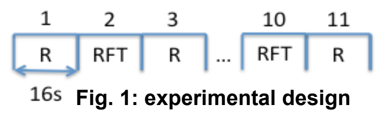

Fig. 1: experimental design

Discussion and Conclusion: One-step thresholding is as computationally efficient as conventional methods. It avoids complex nonlinear techniques that are commonly used in the compressed setting. The proposed method accurately detected the significant activations in the left primary motor cortex. Scattered single-voxel activations, likely caused by motion, appear more frequently in the OST images than in the reference images. The results indicate high sensitivity of the proposed OST method and a need for further optimization of the specificity.

References: [1] Jung et al., ISBI 2009; [2] Bajwa et al., ISIT 2010; [3] Lustig et al., MRM 2007;

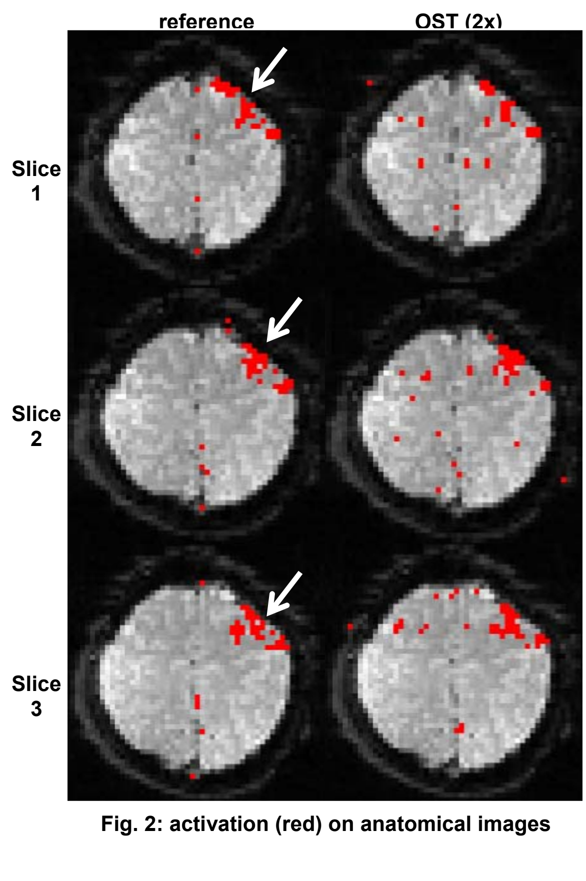

Fig. 2: activation (red) on anatomical images